The International Journal Of Engineering And Science (IJES)
||Volume||2 ||Issue|| 8 ||Pages|| 53-63 ||2013||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Analytical Model to Predict Pore Pressure in Planning High Pressure, High Temperature (Hpht) Wells in Niger Delta.

Nweke, I. Francis
Department of Petroleum and Gas Engineering, University of Port Harcourt, Rivers state, Nigeria.

ABSTRACT
Predicting the pore pressure is the premise of achieving excellent, efficient and safe drilling operation and it is also the key part of protecting oil & gas layer. Agbada basin in the Niger Delta of Nigeria usually has very difficult deep geological structure and multivariate underground pressure system, so it is very significant to efficiently predict its pore pressure in the process of exploration and development of the deep reservoirs in the area.The thesis also analyzes the principle and defect of current prediction methods and finds the proper pore pressure prediction method by modifying Ben Eaton's model, using D-exponent method of pore pressure prediction. The methodology for pore pressure prediction known as D exponent is a function of an exponent of adjustment that was originally defined for the Gulf of Mexico (Jorden & Shirley, 1966; Eaton, 1972). Drilling, Petrophysical and measured pressure data for various wells previously drilled in the area were examined and reviewed.This approach consisted of calculating the ratio between effective stress and the D exponent at each well, in order to find a robust NCT for the entire field, thus reducing subjectivity in the traditional D exponent methodology. Pore pressure determinations from Measured Direct Tests (MDT) at various well in Niger Delta confirm the predictive capability of this approach. This produces a new thought and method for pore pressure prediction of deep formation in Niger Delta and for HPHT wells, this method is impacted by the number of study samples, it should be used in where the measured formation pressure data is rich.

Date of Submission: Date 13Aug. 2013, Date of Acceptance: 30 Aug2013,

I. INTRODUCTION

World energy demand is increasing continuously to meet the need of energy of the developing countries. Increase in the energy consumption rates forces the scientists and engineers to discover another ways of gathering energy or better ways to recover the sources that we have been already using for years.Most of the world's remaining prospects for hydrocarbon resources will be more challenging to drill than those enjoyed in the past. In fact, many would argue that the easy ones have already been drilled. And with oil prices where they are today, drilling safely and cost effectively while producing a good well in the process could not be more important.

Considering all these, pore pressure prediction methods should now be regarded as a technology that may provide a noteworthy increase in cost-effective drill-ability by reducing excessive drilling-related costs typically related with conventional offshore drilling, if most of the world's remaining vision for oil and gas being economically un-drillable with conventional wisdom casing set points and fluids programs are taken into account.Pore pressure greatly affects drilling safety and the economics of drilling design and well construction. Drilling Engineers often use estimated pore and fracture pressure profiles along the well path as primary input to the well design due to their overriding influence on casing seat selection. This, in turn, is the primary driver for hole geometry, casing program, and overall well cost.

The issue of subsurface pore-pressure prediction has a long history, and a long future. Despite a record of some success in prediction (in restricted contexts), we regard the problem to be unsolved to date. The present work offers a new approach; one that differs in kind from all extant algorithms (Scott and Thomsen, 1992). The difficulties in predicting in situ pore pressure from remote measurements are three-fold. First, one can never remotely measure pore pressure itself, but must always measure something else, e.g., seismic velocity. The quantity measured is sensitive to pore pressure, which is then inferred indirectly from the measurement. However, the quantity measured is always similarly sensitive to other factors as well, such as porosity or mineralogy.

Hence, the pore pressure may not be inferred from the measurement without an assumption (or conclusion), explicit or implicit, concerning these other factors. However, these assumptions are rarely considered with care, and the circumstances which may lead to their fulfillment are not known. Hence, the extension of these methods to new areas is usually problematical, requiring new "calibration", and a new set of assumptions, similarly unstated an unanalyzed.The second set of difficulties in pore pressure prediction arises because the measured quantity, e.g., velocity, is inaccurate and poorly resolved. The inaccuracy involves both random errors, and systematic ones. The systematic errors may arise if the raw data (e.g., arrival times of reflected waves) are interpreted via a theory which makes incorrect assumptions (e.g., that the subsurface rocks are isotropic, or that the move out is hyperbolic).

At best, surface reflection data yield only average velocities over the coarse intervals between major reflectors; this poor velocity resolution affects both the accuracy and the positioning of the consequent pressure predictions.A third class of difficulties, less fundamental than the previous ones, arises if a prediction method is calibrated using borehole data which do not represent all the rocks present. For example, some methods are calibrated using sonic velocities from shale intervals only, perhaps selected by a gamma ray log criterion.
It is then clearly inappropriate to apply this directly to prediction using seismic data, which of course samples all the lithologies present, not just the shale. A related issue may arise in the calibration process, if data from shale intervals only are utilized for pressure prediction and compared with pressure data (e.g., RFT data) taken from non-shale intervals. If the comparison reveals differences, there may be a temptation to claim that the pore pressure actually differs between sands and the encasing shale, and that this difference persists over geologic time. If commonly true, this assertion would then invalidate calculations which do assume pressures equilibrated between sands and encasing shale. In any case, it is easy to demonstrate that such a difference requires permeability in the nano-darcy range; a condition which probably requires special circumstances, which are not well understood (Dickey, 1993).

Because of these difficulties, it is clear that the problem of pore pressure prediction has no unique solution. (The problem of estimating pore pressure, in the formations surrounding an existing borehole, is better posed, especially if multiple datasets (e.g., resistivity as well as velocity) are utilized. Of course, it might remain possible to make predictions which are useful in some sense, especially if appropriate uncertainties are assigned. To this end, it is helpful to have available various prediction algorithms which differ from one another in kind, rather than in degree. Where independent algorithms agree in their predictions, one has added confidence; where they disagree, one concentrates further analysis. Some algorithms do have substantial independence from all algorithms in the literature and hence may be useful in this regard. Most previous algorithms utilize the data of a given point (or a given layer) to estimate, or predict, the pore pressure in that layer, independently for each layer. This may be characterized as the physicist's viewpoint, regarding each layer independently, like different samples in a laboratory. By contrast, they are ones that recognizes that the various layers are not independent, but are coupled together via geologic process and history, portions of which we understand. This may be characterized as the geophysicist's viewpoint.

In recent years, the oil companies operating in Niger Delta have successfully employed pore pressure prediction to design cost-effective wells and avoid drilling hazards. Unfortunately, formation pressures can be very difficult to quantify precisely where unusual, or abnormal, pressures exist. Pore pressure prediction technology continues to improve, taking advantage of newly acquired knowledge from recent deepwater drilling, new seismic acquisition, new algorithms, and powerful computation power.

There are many causes for abnormal pressure, and failure to consider all factors may produce poor pore pressure prediction and eventually result in well abandonment, expensive sidetracks, well blowout, and stuck drill pipe, not to mention other potential drilling hazards associated with abnormal pressure.Accurate pore pressure predictions are required for the drilling engineer to make an efficient well plan in terms of casing design, mud weights, drilling time and safety. It is made even more critical as the industry drills more expensive wells to deeper horizons, in more complicated geology, and with more complex well bore architectures, where wells are more expensive and problems can be more spectacular.

To meet today’s challenge of high drilling costs and green environmental requirements, the areas to be outlined in this research work need to be well understood and executed to obtain accurate and qualitative pore pressure information. Pore pressure of formations is one of the big problems facing drillers in exploration areas today. The pore pressure, together with fracture gradient, determines the mud weight that is needed. Too much mud weight fractures the rock, too little mud weight allows formation fluids to come into the well and can cause blow-outs if not controlled.

Real-time pore-pressure prediction ahead of the bit, therefore providing a way of telling what pressures are expected ahead of the bit.The third approach to pore-pressure prediction ahead of the bit is the look-ahead impedance inversion using VSP data. If the pore-pressure change is associated with a sharp change in acoustic impedance, then the look-ahead imaging could work well. However, this approach does not work in cases where the pore pressure builds up gradually and it is not associated with a sharp impedance change. In this case there would not be a seismic reflection event from the pore pressure zone and there would not be a well-defined pore-pressure “target” on the look-ahead image.

Predrill pressure prediction has historically been done using very simple models and overly simplistic estimates of the earth's velocity field. The methods usually incorporate a locally calibrated set of curves for pressure. The advent of the effective stress concept and pressure prediction methods that developed from that concept has led to a much-needed inclusion of fundamental physics into the art of pressure prediction. The use of effective stress methods has become the standard for pressure prediction. This technique has many variants including the Eaton method, the Bowers method, and the Sperry Sun method. The issue of subsurface pore-pressure prediction has a long history, and a long future. Despite a record of some success in prediction (in restricted contexts) via the "classical algorithms", we regard the problem to be unsolved to date. The present work offers a new approach; one that differs in kind from all extant algorithms (Scott and Thomsen, 1992).

The difficulties in predicting in situ pore pressure from remote measurements are three-fold. First, one can never remotely measure pore pressure itself, but must always measure something else, e.g., seismic velocity. The quantity measured is sensitive to pore pressure, which is then inferred indirectly from the measurement. However, the quantity measured is always similarly sensitive to other factors as well, such as porosity or mineralogy.Hence, the pore pressure may not be inferred from the measurement without an assumption (or conclusion), explicit or implicit, concerning these other factors. The successes of the classical algorithms (e.g., Mouchet and Mitchell, 1989) result usually from the fulfillment of their implicit assumptions concerning these other factors.

However, these assumptions are rarely considered with care, and the circumstances which may lead to their fulfillment are not known. Hence, the extension of these methods to new areas is usually problematical, requiring new "calibration", and a new set of assumptions, similarly unstated an unanalyzed. The second set of difficulties in pore pressure prediction arises because the measured quantity, e.g., velocity, is inaccurate and poorly resolved. The inaccuracy involves both random errors, and systematic ones.

The systematic errors may arise if the raw data (e.g., arrival times of reflected waves) are interpreted via a theory which makes incorrect assumptions (e.g., that the subsurface rocks are isotropic, or that the move out is hyperbolic). At best, surface reflection data yield only average velocities over the coarse intervals between major reflectors; this poor velocity resolution affects both the accuracy and the positioning of the consequent pressure predictions. A third class of difficulties, less fundamental than the previous ones, arises if a prediction method is calibrated using borehole data which do not represent all the rocks present. For example, some methods are calibrated using sonic velocities from shale intervals only, perhaps selected by a gamma ray log criterion. It is then clearly inappropriate to apply this directly to prediction using seismic data, which of course samples all the lithologies present, not just the shale.

A related issue may arise in the calibration process, if data from shale intervals only are utilized for pressure prediction and compared with pressure data (e.g.,RFT data) taken from non-shale intervals. If the comparison reveals differences, there may be a temptation to claim that the pore pressure actually differs between sands and the encasing shale, and that this difference persists over geologic time. If commonly true, this assertion would then invalidate calculations which do assume pressures equilibrated between sands and encasing shale. In any case, it is easy to demonstrate that such a difference requires permeability in the non-Darcy range; a condition which probably requires special circumstances, which are not well understood (Dickey, 1993).

Because of these difficulties, it is clear that the problem of pore pressure prediction has no unique solution. (The problem of estimating pore pressure, in the formations surrounding an existing borehole, is better posed, especially if multiple datasets (e.g., resistivity as well as velocity) are utilized.) Of course, it might remain possible to make predictions which are useful in some sense, especially if appropriate uncertainties are assigned. To this end, it is helpful to have available various prediction algorithms which differ from one another in kind, rather than in degree. Where independent algorithms agree in their predictions, one has added confidence; where they disagree, one concentrates further analysis. Weaknesses remain due to:

(1) Limitations of the seismic velocities themselves.
(2) Lack of understanding of the basic causes of pressure.
(3) Effects of pressure on physical properties (including velocity, density, and porosity) of rocks.

The level of sophistication used in pressure prediction has improved steadily over the last few years, and the future looks even more promising. This thesis will discuss some critical challenges facing pore-pressure prediction and some solutions on the horizon.

II. PROBLEMS WITH PAST WORK ON PORE PRESSURE PREDICTION

Attempt has been made here to bring to fore some past works on pressure modeling of published, to highlights their merits and demerits as well using some of the lessons learnt in developing a model for the Niger Delta.

1) Perhaps the most widely publicized pore-pressure-estimation technique is Eaton's method (1972), The exponents like the over burden, resistivity, sonic delta t, are typical values that are often changed for different regions so that the predictions better match pore pressures inferred from other data. The major problem with all trend-line methods is that the user must pick the correct normal compaction trend. Sometimes are too few data to define the NCT. Unfortunately, if the NCT is defined over an interval with elevated pore pressure, the method will give the wrong (too low) pore pressure, leading to severe risks for drilling. Geology of an area is a major challenge, so the indirect methods were developed and tested in discrete areas of the world, where the local geology may not be comparable to that in other basins. Models that depends on petrophysical data like resistivity of the rocks might give a wrong predictions based on high salinity of the fluid content of the rock.
2) It is important to realize that, in contrast to Terzaghi's methods (......), the Hottman and Johnson's method (........) does not use overburden or effective stress explicitly and thus is not an effective stress method. This can lead to unphysical situations, such as calculated pore pressures that are higher than the overburden.
3) Bourgoyne A. T. et al (1986), in the in SPE textbook series, Vol.2 titled "Applied Drilling Engineering." Developed model based on porosity variable parameters with respect to depth for pressure estimate for Gulf coast of USA. The porosity dependable parameter is plotted against depth and based on comparison with expected normal trend, the pressure is calculated based on the assumption that formations having the same value of the porosity parameter (interval transit time) are under vertical matrix stress, az. or the relationship developed by Pennebaker (1968). Both results show slight variation in predicted pressure however the degree of confidence is not defined as the work was done deterministically based on average values.
4) A classical work presented by P.M Doyen (2004) used an extension of Bowers Formula (BOWERS G.L., 2003) Starting with the work of (SAYER, 1995.). It links pore pressure to seismic velocity, overburden stress, porosity and clay volume. Probability Distribution Functions (PDF) of these input variables are stored as attributes in the developed 3D Mechanical Earth Model. In order to generate data for the input variable, it will require drilling quite a number of wells in an area to have an idea on variables like clay content. Also overburden on itself has a direct relationship with the pore pressure. Also, in all nine variables were involved in generating the PDF if the numbers of variables were lesser; the degree of uncertainty associated with the prediction will be altered.
5) In the IADC/SPE paper titled "Pre-drill pore pressure prediction using seismic data, (SAYERS et al, 2002) Seismic tomography was used in deriving accurate velocities in place of stacking velocity. This is to remove the assumption of hyperbolic movement of staking velocity. Application of ray theory is then used to predict highly accurate inversion sequence for accurate interval velocities. Therefore the use of tomography velocities instead of stacking velocity will be an enhancement in predictive pressure modeling.
6) Use of reflection tomography to predict pore pressure in over pressured sands by (SAYERS, 2003) further reinforce the use of more accurate velocity data in predicting pore pressure using the extended Bowers Formula while the results are also good, a lot of wells need to have been drilled to have the clay content definition for the field therefore this work also suffers the same fate as that of Doyens for fields with few wells.
7) In IADC/SPE 59125 paper, compaction theory which uses the relationship between *VP/VS* and vertical effective stress, Poisson ratio were used in evaluating pore pressure in East Sichuan, China. Although the result were good, for abnormally high pressure more work need to be done. The use of *VP/ VS* was as a result of the greater sensitivity to pore pressure in limestone. The present work is set in a sand-shale formation environment.

III. OBJECTIVE AND SCOPE OF WORK

The basic aim of this research work is to involve a variety of seismic and drilling activities in order to improve pore pressure prediction in planning HPHT wells in Niger Delta region. Closing the gaps and inadequacies related to jobs done already in pore pressure prediction. This will be achieved through:

• Surveying the "state of the art" in both pore pressure prediction and fracture gradient prediction as they exist today in terms of the models, methods and assumptions being used by the industry.
• Evaluating best practice methodology for processing seismic velocity data for estimating pore pressures.
• Studying the methods and approaches the industry uses to estimate formation pressure.
• Constructing a database of pressure-related data from so many wells (virtually all area in Niger Delta; Land, Swamp, offshore and Deep water) with a detailed pore pressure analysis of field using all available data, and preparing a comprehensive written report for each field that detailed the methods and models used and included extensive graphic reports; and lastly
• Developing a new analytical model and method to predict pore pressure in planning high temperature high pressure wells in Niger Delta region.

Once the causes of abnormal pore pressure are understood, the key to successful pore pressure prediction is to construct a pressure model that accounts for those causes.

First, a theoretical pressure model will be developed to transform geologically calibrated seismic interval velocities to pore pressure, taking into account under compaction, and fluid dynamics.

Secondly, well and drilling information, including logs, mud weights, temperature gradient, leak-off test, repeat formation test, etc., will be incorporated to build the final calibrated pressure model by fine-tuning certain coefficients in the theoretical formulas. This calibrated pressure model will be applied for local geology in a particular project.

IV. METHODOLOGY

The workflow implemented to analyze and ultimately choose the best pore pressure prediction strategy is outlined below. This workflow was performed for a lot of offset wells in Niger Delta region.

1. Identify, acquire and review offset wells data in Niger Delta including;
• Petrophysical and seismic data.
• Drilling records.
• Measured pressure data.
2. Construct pore pressure prediction model using petrophysical and seismic data.
3. Include offset well data in the pore pressure prediction model.
4. Calibrate pore pressure prediction model, if necessary.
5. Analyze pore pressure prediction model against data obtained from reviewing drilling records and select or develop a near accurate pore pressure prediction model for planning HPHT wells in Niger Delta.

New Analytical Model For Pore Pressure Prediction (Modified Eaton's Equation)

The D exponent methodology was developed with the goal of normalizing the penetration rate from drilling parameters. The method was proposed by Jorden and Shirley (1966) based on the Bingham (1969) equation, which was developed to consider the differential pressure effect in normalizing penetration rate. Rehm and Mcledon (1971) modified Jorden & Shirley's equation to include mud weight, as shown in Equation 1. This expression is known as the D exponent equation, calculated from

$$D = \frac{Log\left(\frac{R}{60N}\right)}{Log\left(\frac{12W}{10^6 D}\right)} * \left(\frac{\rho_{normal}}{\rho_{actual}}\right) \qquad \text{………………………………………1}$$

Where:

R = Penetration rate (ft/h)

N = RPM (Revolutions per minute)

D = Bit diameter (in)

W = Weight on the bit (lb)

ρ_{normal} = Normal hydrostatic gradient (ppg)

ρ_{actual} = Current mud weight (ppg)

This method quantifies the correlation between 'drillability' (the bit's capacity of perforating through a rock interval) and overpressured shale sequences found offshore Louisiana using tri-conic bits (Jorden & Shirley, 1966; Rehm & McCledon, 1971; and Moutchet & Mitchell, 1989). The equation also considers the effect of the overburden gradient.

The geologic setting of the Niger Delta fields is obviously different from the geology of the Gulf of Mexico. The sedimentary sequence in the Niger Delta, for example, includes alternations between sand and shale deposited in shallow marine environments. In addition, the Niger Delta foothills are being subjected to lateral stresses of large magnitude, where the maximum horizontal stress is several times larger than the vertical stress (Torres, 2001; Uribe & Solano, 2006).

An advantage of this method is that the results can be obtained in real time, as drilling parameters are collected through sensors. Any other information obtained by the Mud Logging Unit can also be used to detect formation pressure changes. For example, changes in drilling fluid such as total gas content, temperature, density, salinity, etc or changes in characteristics of the formation samples gathered in the shale shaker, such as density, shape and amount, may relate to zones of overpressure (Moutchet & Mitchell, 1989).The procedure used for estimation of the pore pressure profile from the D exponent is based on Eaton's correlation (Equation

2.0) below, (Eaton, 1972), using the adjustment parameter F^a determined from the D Exponent. Eaton's correlation is defined by:

$$\frac{p}{z} = \frac{s}{z} - \left[\frac{s}{z} - \frac{p_n}{z}\right] * f^{\alpha}$$

………………………………………….2

Where p is pore pressure, z is depth, P_n is normal pressure, p/z is the pore pressure gradient (psi/ft), s/z is the overburden pressure gradient (psi/ft), $\mathbf{P}_n/Z$ is the normal pore pressure gradient (psi/ft), and f^a is the adjustment parameter.

The adjustment correlation parameter f^a, depends on the type of data available, which may be either seismic, sonic, resistivity, or conductivity logs, drilling parameters, etc. According to the above, the following equation is a function of drilling parameters only:

$$\frac{p}{z} = \frac{s}{z} - \left[\frac{s}{z} - \frac{p_n}{z}\right] * \left[\frac{D}{D_n}\right]^b$$

……………………………………..2.1

Where: D is the D exponent, and D_n is the normal trend of the D exponent (Normal Compaction Trend, NCT). Eaton (1972), using this methodology in the Gulf coast proposed that the exponent b in Equation 8.1 varies between 1,2-1,5. This exponent depends on the regional geologic setting, since it involves the overburden and pressure gradient.The methodology for pore pressure prediction known as D exponent is a function of an exponent of adjustment that was originally defined for the Gulf of Mexico (Jorden & Shirley, 1966; Eaton, 1972). A limiting factor of this methodology is the definition of the Normal Compaction Trend (NCT), which needs to be interpreted from the data (Mouchet & Mitchell, 1989). In this study, the D exponent methodology was modified to make it applicable to the Niger Delta Formation in various oil field in Nigeria.

The approach consisted of calculating the ratio between effective stress and the D exponent at each well, in order to find a robust NCT for the entire field, using the trend to predict for the deep zones of high pressure high temperatures formations in Niger Delta, thus reducing subjectivity in the traditional D exponent methodology. Pore pressure determinations from Measured Direct Tests (MDT) at various well in Niger Delta confirm the predictive capability of this approach.

The D exponent methodology provides at least three main operating advantages (Moutchet & Mitchell, 1989): it is a low cost methodology and thus has a minor financial impact on exploration; the method can be performed in real time during drilling; implementation and application is simple, and does not require highly skilled personnel. As it was mentioned earlier, however, the fundamental goal of this study was to derive a less subjective analytical approach to calculating the pore pressure starting from the methodology of the D exponent, applied to all Niger Delta Formation.

For pore pressure determination, two methodologies were applied on several wells of the study area. The first approach consisted of applying the standard D exponent method, defining several reasonable Normal Compaction Trends (NCTs) based upon changes in bottom hole assemble, hole diameter, lithology, geologic age, etc. Each NCT defined in this manner results in a different estimate of pore pressure (Figure 1) below. For the Niger Delta region, values of b in Equation 8.1 between 1 and 1.2 were found most appropriate to estimate pore pressure from conductive, resistivity and drilling parameter logs, while for sonic logs b is closer to 3,0 (Eaton, 1972). In this study, values of b between 1.0 and 1.2 were found appropriate for pore pressure estimation in the most Niger Delta fields from sonic logs and drilling parameter logs.

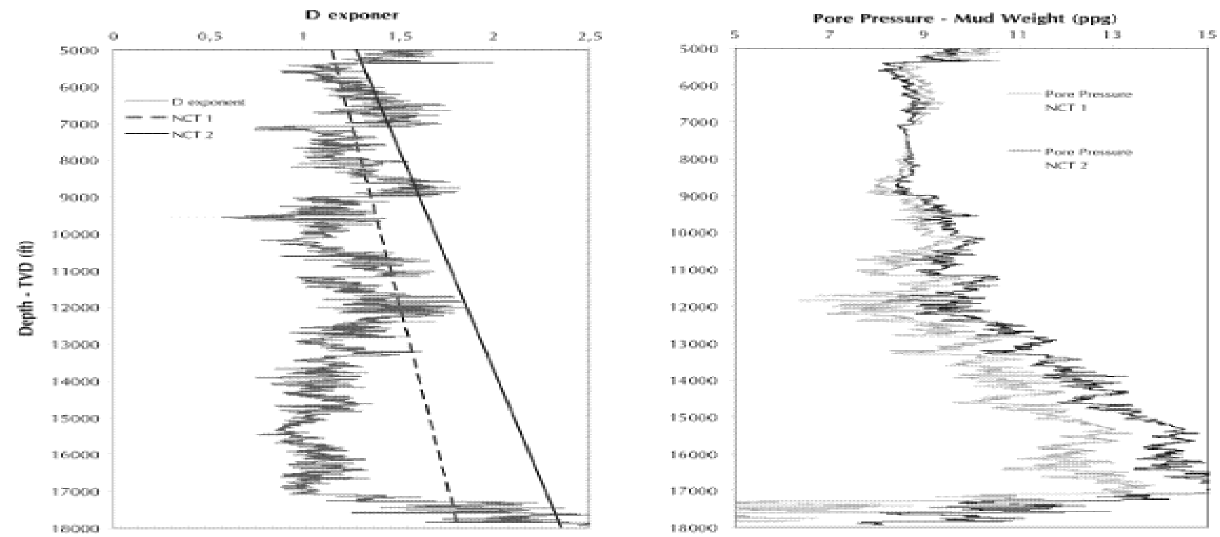
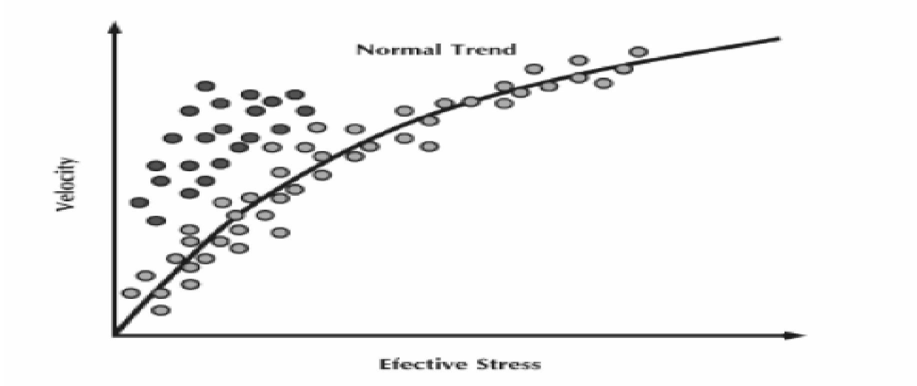


Figure 1. A. user-defined normal Compaction Trends (NCT). B. Variation of pore pressure calculated with several Normal Compaction Trends (NCT)

The second approach also applies the D exponent method, but in this case the NCT is derived from a plot of effective stress versus D exponent for all wells in the field. This approach was devised because in normally pressured sediments, D exponent is expected to increase with depth. In addition, effective stress is expected to increase with depth in normally compacted sediments. Therefore, deviations from a trend line in a plot of effective stress versus D exponent should be related to deviations from normal pore pressure.

This approach was based on observations by Bowers (1995), who related seismic velocity to effective stress. He recognized that pore pressure can be estimated using the ratio between effective stress and velocity in normally pressured sediments, while values outside the NCT correspond to abnormal pressures.



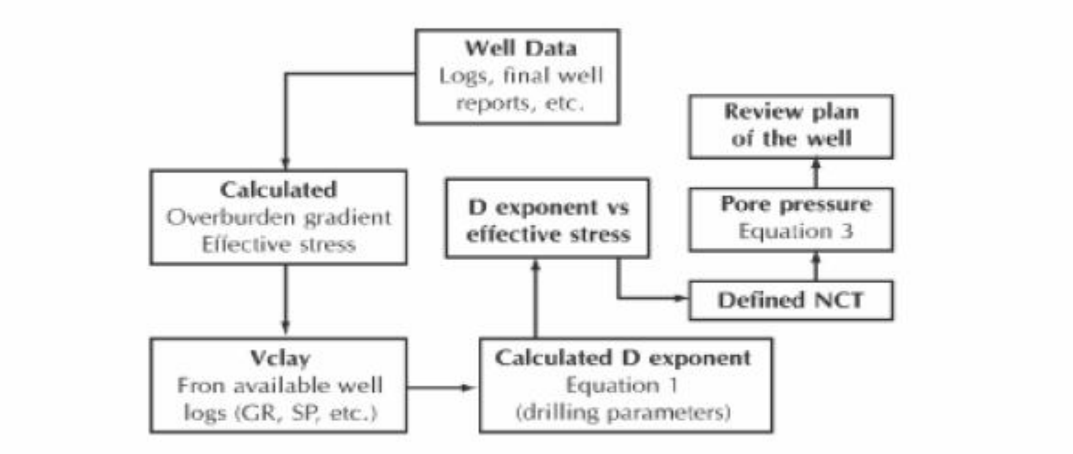
This approach was applied according to several considerations. A database of gamma ray, sonic, and density logs, pressure tests (MDT/RFT, event drillings, formations tops, etc., were compiled. Calculations must be made in TVD (True Vertical Depth). In addition, the normal overburden gradient needs to be calculated as an input to Equation 8.0 and for estimation of effective stress.

The first step is calculating the overburden gradient and the effective stress. The overburden gradient can be calculated from density logs using standard techniques (Moutchet & Mitchell, 1989). Estimation of effective stress can be accomplished using Terzaghi's equation (Therzaghi, 1968). The second step in this approach consisted in calculating the clay volume (VClay) from available well logs. Subsequently, depth, VClay, effective stress, mud weight and D exponent data are grouped by geological formation. Outliers are identified and removed from the data set.

$$P_F = \sigma_{OB} - \sigma_{EV} \qquad \textit{(Equation 2.1)}$$

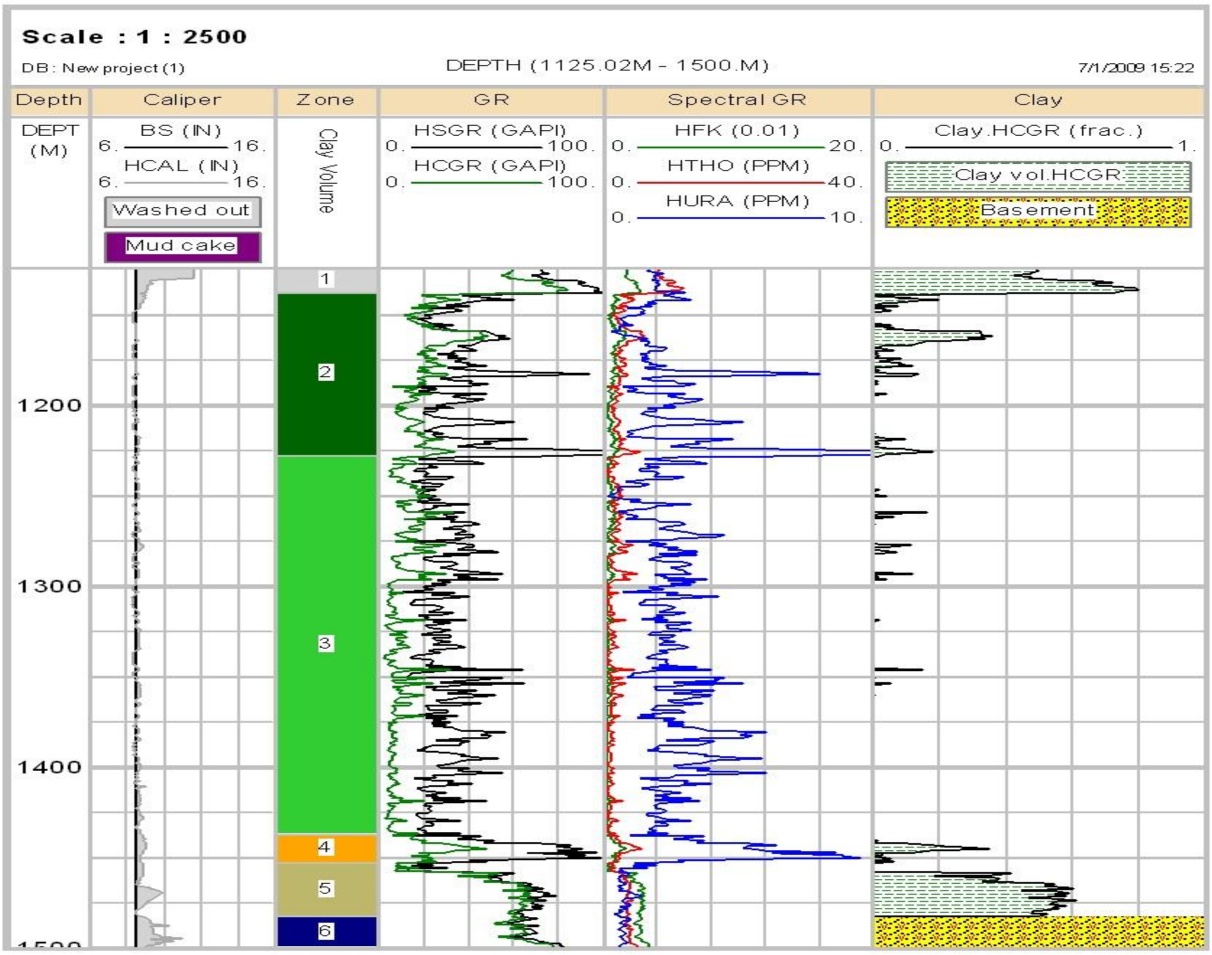
Next, a graph of D exponent versus effective stress is built from all data points. A best-fit function is then calculated from the data points that fall in the normally compacted section. This function is used to obtain

the normal trend of the D exponent D_n. Finally, Equation 8.1 is solved for the interval of interest at each well. The above procedure is summarized in the flow chart below.



The approach developed in this study was performed on data from several wells drilled in Niger Delta. For the study area, an overburden gradient of 1,05 psi/ft was estimated. A normal pore pressure gradient of 0,449 psi/ft, taken from the first direct pressure tests performed in the area, was also used in Equation 8 and for estimation of effective stress using Terzaghi's equation (Terzaghi, 1968).

For VClay calculation in this area, the GR logs were deemed to provide the best input data. Therefore, VClay was calculated from GR logs, using a cutoff of 0.35. Subsequently, the D exponent versus effective stress plot was built from all data (over 25 000 points).



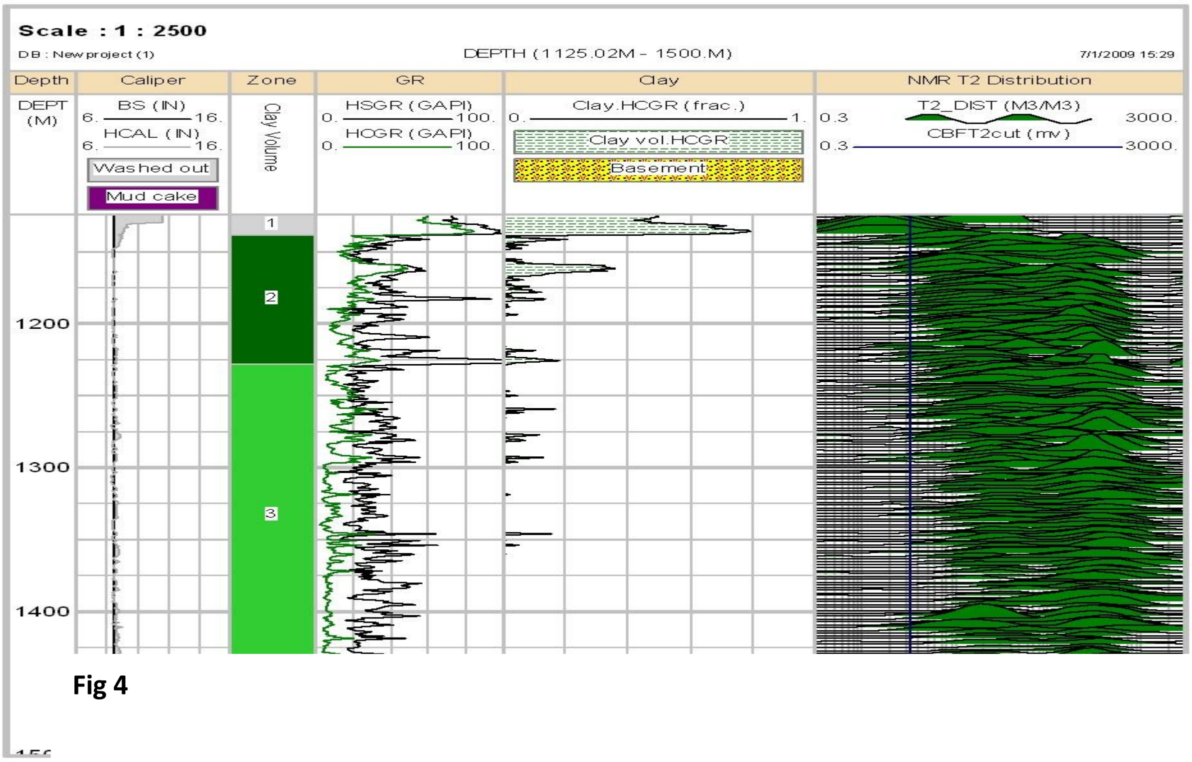


Fig 4

The function that best represents the NCT for the data

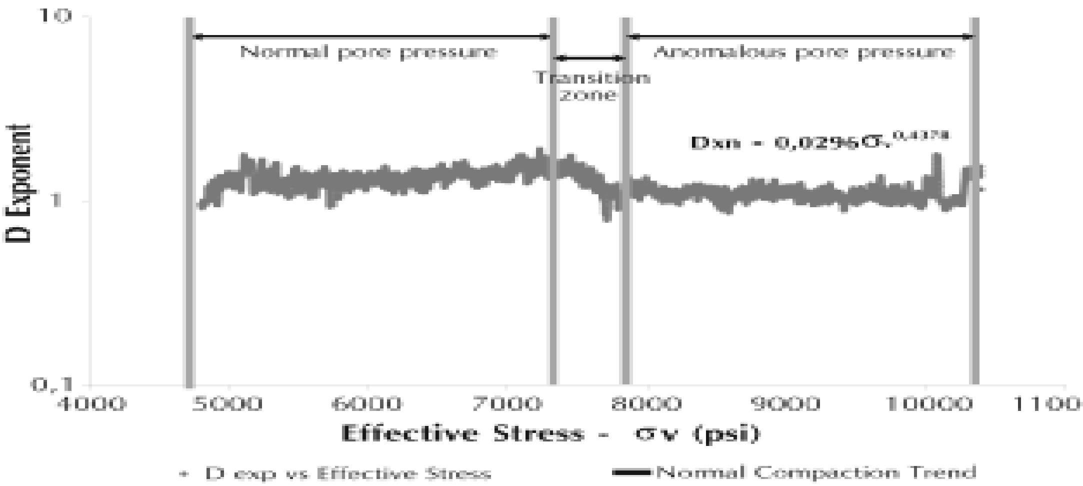


Figure 4. D exponent versus effective stress for all data points available in the field. Note that the NCT of the field is represented by the trend line fit to data from the upper Carbonera Formation

s a power law function of the form

$$Dxn = 0,0296 * \sigma_v^{0,4378} \qquad (8.3)$$

Where D_{xn} is the NCT and **sv** is the effective stress in psi.

Although a linear trend can be fit on these points with a slightly higher R2 coefficient than Equation 2.2, the power law function worked best on the well where pressure tests (MDT) of the Agbada Formation are available.

Pore pressure was obtained by replacing D_{xn} in Equation 1. The b exponent found with this approach was in the range of 1,0 to 1.2 (Equation 2.1).

In addition to the NCT of the field, Figure 4 shows zones of departure from normal pressure conditions. An intermediate zone is shown where data begin to deviate from the NCT. This transition zone is characterized by a rapid decrease in D exponent (from 1,6 down to 0,9) over a short interval of effective stress. Abnormal pore pressure conditions are observed to the right of the transition zone in Figure 4, where D exponent data are completely off the NCT. In this case, abnormal pore pressure conditions are evidenced for nearly constant D exponent values that fall under the NCT line Figure 4.

To examine the validity of the proposed approach, comparison were made with results of measured direct tests (MDT) data from several wells. Pressure tests are uncommon in the overburden column –namely the Agbada Formation- in this area. Some wells is an exception, since 8 MDT data points were taken on the Agbada Formation and were made available for this study. Figure 6 shows comparison between the standard approach and the proposed approach with MDT data. Note that this approach honors 7 points, while the standard method only honors 3 points. Note also that this approach is consistent with mud weight, which is an indicator of the actual well conditions while drilling.

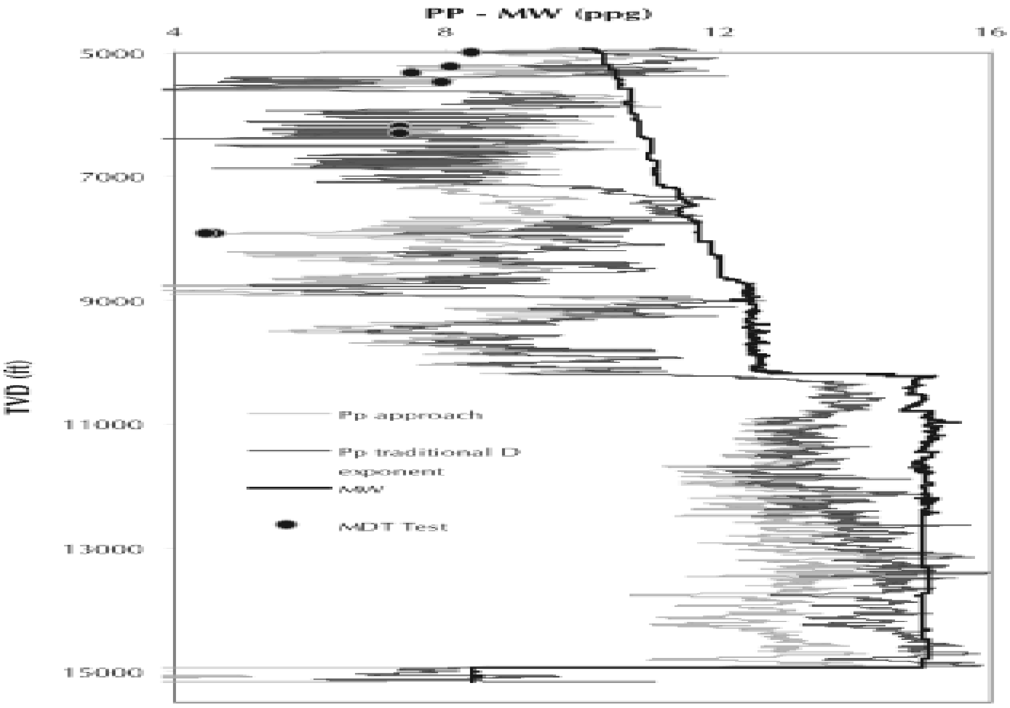


Figure 6. Pore pressure well 10 with pressure test

V. CONCLUSION

- By using the ratio between D exponent and effective stress, pore pressure can be estimated more accurately than the standard D exponent method for Niger Delta formations. This approach is more objective for definition of the normal compaction trend, because the NCT is defined for the entire field rather than for individual wells.
- Abnormally pressured sections of the Agbada Formation were easily identified using the proposed approach.
- Establishment an adjustment exponent b for the Agbada Formation in the study area using the standard D exponent method. This exponent varies from 1.0 to 1.2, in clear contrast with the 1.2 to 3 range that is widely used worldwide based on data from the Gulf of Mexico and several oil fields in the world. The D exponent found for the modified approach is 1,0.
- This study confirmed that the standard D exponent methodology as well as the proposed approach provides reasonable pore pressure determinations before and during drilling operations.

BIOGRAPHY:

- Nweke, I. Francis, had a first degree in Petroleum Engineering from Federal University of Technology, Owerri, Imo State, Nigeria. He obtained his masters degree in Gas Engineering from University of Port Harcourt, Rivers state, Nigeria and currently a Ph D student in the same University of Port Harcourt, where he is carrying out research on pore pressure prediction in planning HPHT wells.
- He is currently working as a Senior Drilling Engineer in Nigerian Agip Oil Company (Eni International) with 12 years working experience in Drilling and Completion Engineering.
- He is a member, Society of Petroleum Engineers, International (SPE). Membership number: 3001075.
- Registered member - Council for the Regulation of Engineering in Nigeria - (COREN). membership number : R. 15,511

REFERENCES

[1] Whiteman, A.: Nigeria: its Petroleum Geology, resources and potential, Vols 1 & 2, Graham & trotman Ltd., London, 1982.

[2] Ichara, M.J and Avbovbo, A.A.: How to handle Abnormal pressure in Nigeria's Niger Delta Area, Oil and Gas J., Mar. 11 1985.

[3] Schlumberger: well evaluation Conference, Nigeria, 1985, pp113-132.

[4] Prediction of abnormal pressures in the Niger Delta basin using well logs: Olubunmi O. Owolabi, Godwin A. Okpobiri, Iyalla A. Obomanu.

[5] Prediction of overpressure in Nigeria using vertical seismic profile techniques: S. Brun, P. Grivelet and A. Paul.

[6] Eaton, B.A.: "Fracture Gradient Prediction and Its Application in Oilfield Operations," JPT, October 1969.

[7] Eaton, B.A., and Eaton, L.E.: "Fracture Gradient Prediction for the New Generation," World Oil, October 1997.

[8] Eaton, B.A.: "The Equation for Geopressure Prediction from Well Logs," paper SPE 5544 presented at the 1975 SPE Annual Technical Conference and Exhibition, Dallas, TX. September 28 – October 1.

[9] Gardner, G.H.F., et al.: "Formation Velocity and Density – The Diagnostic Basis for Stratigraphic Traps," Geophysics, Vol. 39, No. 6, December 1974.

[10] Hottman, C.E., and Johnson, R.K.: "Estimation of Formation Pressures from Log-derived Shale Properties," JPT, June 1965, p. 717.

[11] Matthews, W.R.: "Here is How to Calculate Pore Pressure from Logs," OGJ, November 15, 1971 – January 24, 1972.

[12] MI Drilling Fluids, Inc.: "Plotting Pressures From Electric Logs," 1999. Schlumberger: "Oilfield Glossary – Where the Oilfield Meets the Dictionary," http://www.glossary.oilfield.slb.com.

[13] Schlumberger: "Log Interpretation Charts," Houston, Tx, 1979.

[14] Terzaghi, K.: "Theoretical Soil Mechanics," John Wiley and Sons, New York City, NY, 1943.

[15] Timur. A., et al.: "Porosity and Pressure Dependence on Formation Resistivity Factor for Sandstones," Cdn. Well Logging Soc., 1972, 4, paper D.

[16] Winsauer, H.M., et al.: "Resistivity of Brine-Saturated Sands in Relation to Pore Geometry,"

[17] AAPB Bulletin 36, No. 2, February 1952, pp. 253 – 277.

[18] Yoshida, C., et al.: "An Investigative Study of Recent Technologies Used For Prediction, Detection, and Evaluation of Abnormal Formation Pressure and Fracture Pressure in North and South America," IADC/SPE 36381 presented at the 1996 IADC/SPE Asia Pacific Drilling Technology Conference, Kuala Lumpur, Malaysia, September 9 – 11.

[19] Gerbaud, L., Menand, S., and Sellami, H. 2006. PDC Bits: All Comes From the Cutter/Rock Interaction. IADC/SPE Drilling Conference, 21-23 Feb, Miami, Florida, USA. SPE #98988-MS.

[20] Handin, J., Hager, R., Friedman, M., and Feather, J. 1963. Experimental Deformation of Sedimentary Rocks Under Confining Pressure: Pore Pressure Tests. Bulletin of the American Association of Petroleum Geologists. Volume 47 Number 5.